CHAPTER 5

CSS MONITORING

This chapter describes how to monitor rainfall, combined sewer system (CSS) flow, and CSS water quality, and describes procedures for organizing and analyzing the data collected. It discusses a range of monitoring and analysis options and provides criteria for identifying appropriate options.

5.1 THE CSO CONTROL POLICY AND CSS MONITORING

The CSO Control Policy identifies several possible objectives of a CSS monitoring program, including:

- To gain a thorough understanding of the sewer system
- To adequately characterize the system's response to wet weather events, such as the volume, frequency, and duration of CSOs and the concentration and mass of pollutants discharged
- To support a mathematical model to characterize the CSS
- To support development of the long-term control plan (LTCP)
- To evaluate the expected effectiveness of a range of CSO control options.

CSS monitoring also directly supports implementation of the following elements of the nine minimum controls (NMC):

- Maximum use of the collection system for storage
- Maximization of flow to the POTW for treatment
- Control of solids and floatable materials in CSOs
- Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls.

CSS monitoring will also support the in-depth system characterization and post-construction compliance monitoring that are central elements in the LTCP.

This chapter outlines the steps that are critical to collection and analysis of rainfall, flow, and water quality data in accordance with the CSO Control Policy.

5.2 RAINFALL DATA FOR CSS CHARACTERIZATION

Rainfall data are a vital part of a CSS monitoring program. This information is necessary to analyze the CSS, calibrate and validate CSO models, and develop design conditions for predicting current and future CSOs. Rainfall data should include long-term rainfall records and data gathered at specific sites throughout the CSS.

This section describes how to install and use rainfall monitoring equipment and how to analyze the data gathered.

5.2.1 Rainfall Monitoring

The permittee's rainfall data will probably include both **national** and **local** data. National rainfall data are available from a number of Federal and local sources, including the National Weather Service, the National Climatic Data Center (NCDC), airports, and universities (see Chapter 3). Because rainfall conditions vary over short distances, the permittee will probably need to supplement national data with data from local rainfall monitoring stations. Wastewater treatment plants may already collect and maintain local rainfall data. If sufficient local rainfall data are not available, the permittee may need to install rain gages. Where possible, the permittee should place gages in every monitored CSO basin because of the high spatial variability of rainfall.

Equipment

Two types of gages are used to measure the amount and intensity of rainfall. A **standard** rain gage collects the rainfall directly in a marked container and the amount of rain is measured visually. Although inexpensive, standard gages do not provide a way to record changes in storm intensity unless frequent observations are made during the storm.

Because wet weather flows vary with rainfall intensity, CSS monitoring programs typically use **recording** gages, which provide a permanent record of the rainfall amount over time. The three most common types of recording gages are:

- ***Tipping Bucket Gage*** - Water caught in a collector is funneled into a two-compartment bucket. Once a known quantity of rain is collected, it is emptied into a reservoir, and the event is recorded electronically.

- ***Weighing Type Gage*** - Water is weighed when it falls into a bucket placed on the platform of a spring or lever balance. The weight of the contents is recorded on a chart, showing the accumulation of precipitation.

- ***Float Recording Gage*** - Rainfall is measured by the rise of a float that is placed in the collector.

It is possible to save money by using a combination of standard and recording gages. Placing recording gages strategically amid standard gages makes it possible to compare spatial variations in total rainfall at each recording gage with the surrounding standard gages.

Equipment Installation and Operation

Rain gages are fairly easy to operate and provide accurate data when installed and used properly. Some installation recommendations are as follows:

- Gages should be located in open spaces away from the immediate shielding effects of trees or buildings.

- Gages should be installed at ground level (if vandalism is not a problem) or on a rooftop.

- Police, fire, public works, or other public buildings are desirable installation sites.

5.2.2 Rainfall Data Analysis

The permittee should synchronize rainfall monitoring with CSS flow monitoring, so that rainfall characteristics can be related to the amount of runoff and CSO volume and a CSS model can be calibrated and validated. In addition, long-term rainfall data gathered from existing gages are necessary to develop appropriate design conditions for determining existing and future CSO impacts on receiving water bodies. Because precipitation can vary considerably within short distances, it is usually necessary to use data from several rain gages to estimate the average precipitation for an area.

Development of Design Conditions

Using rainfall data for planning purposes involves development of a "design storm." A design storm is a precipitation event with a specific characteristic that can be used to estimate a volume of runoff or discharge of specific recurrence interval. Design conditions can be estimated if historic rainfall data (such as data from NOAA's National Climatic Data Center) exist that:

- Extend over a sufficient period of time (30 or more years is preferable; 10 is usually acceptable); and
- Were collected close enough to the CSS's service area to reflect conditions within that area.

Common methods for characterizing rainfall include total volumes, event statistics, return period/volume curves, and intensity-duration-frequency curves. These are described below.

Total Volumes. The National Weather Service publishes annual, monthly, and daily rainfall totals, as well as averages and deviations from the average, for each rain gage in its network. The time period for detailed simulation modeling can be selected by:

- Identifying wet- and dry-year rainfalls by comparing a particular year's rainfall to the long-term average; and
- Identifying seasonal differences by calculating monthly totals and averages.

Simple hydraulic models can be used to predict total volumes of runoff, which can be used to identify typical rainfall years and the variations across years. For example, 38 years of rainfall records, 1955-1992, were collected at a NOAA gage near (but not within) a CSS drainage area. These records indicate an average of 44 storm events per year, with a wide variation from year to year. To generate runoff predictions for the CSS drainage area, the STORM runoff model (HEC, 1977) was calibrated and run using the 38 years of hourly rainfall data. The model predicted the number of runoff events per year, the total annual runoff, and the average overflow volume per event in inches/land area. Exhibit 5-1 ranks the years based on the number of events, inches of runoff, and average runoff per event predicted by the model. Results showed the year 1969 had both the highest number of runoff events (68) and largest total runoff volume (15.1 inches). The year 1967 had the highest predicted average overflow per event (0.33 inches).

Exhibit 5-2 lists minimum, maximum, mean, and median values for the modeled runoff predictions based on the data in Exhibit 5-1 for the example site. These statistics identify typical and extreme years to select for modeling or predicting the frequency of overflows under various control alternatives. Long-term computer simulations of the CSS using a multi-year continuous rainfall record, or one-year simulations using typical or wet years, are useful for assessing alternative long-term control strategies.

The data generated by the STORM model can be reviewed for typical or extreme years to determine the uniformity of the monthly distribution of runoff. The years 1969 and 1956 represent extreme high flows. The year 1956 had the most severe event over the 38-year evaluation period, with 6.0 inches of runoff in 30 hours. The years 1970 and 1985 were selected as typical years, having the most uniform distribution of rainfall throughout the year.

For some systems, the permittee may be able to identify typical years and analyze variations by reviewing the rainfall record manually. In these cases, it may not be necessary to use a simple hydraulic model to analyze rainfall data.

Exhibit 5-l. Ranking of Yearly Runoff Characteristics as Simulated by the Storm Model

Rank	Year	No. of Events	Year	Total Runoff (in)	Year	Avg Overflow (in./event)
1	1969	68	1969	15.1	1967	0.33
2	1984	58	1987	14.9	1991	0.31
3	1987	57	1984	14.7	1992	0.30
4	1983	56	1975	14.2	1965	0.30
5	1976	56	1974	13.1	1975	0.27
6	1989	54	1956	13.1	1955	0.27
7	1974	54	1960	12.8	1987	0.26
8	1966	54	1980	12.6	1960	0.26
9	1980	53	1983	12.5	1984	0.25
10	1956	53	1955	12.5	1979	0.25
11	1988	52	1966	12.4	1973	0.25
12	1975	52	1962	12.1	1970	0.25
13	1972	52	1992	12.1	1962	0.25
14	1957	52	1976	12.0	1956	0.25
15	1960	50	1965	12.0	1989	0.24
16	1962	49	1957	11.9	1981	0.24
17	1971	47	1970	11.7	1980	0.24
18	1970	47	1967	11.0	1974	0.24
19	1955	47	1988	10.9	1985	0.23
20	1985	45	1971	10.9	1982	0.23
21	1979	43	1979	10.7	1971	0.23
22	1968	43	1991	10.6	1966	0.23
23	1959	43	1985	10.4	1957	0.23
24	1992	41	1989	9.7	1983	0.22
25	1982	40	1982	9.1	1977	0.22
26	1965	40	1959	8.2	1969	0.22
27	1964	40	1990	8.1	1988	0.21
28	1991	34	1968	7.9	1976	0.21
29	1990	34	1981	7.6	1963	0.21
30	1978	33	1972	7.3	1986	0.20
31	1967	33	1973	7.2	1959	0.19
32	1958	32	1964	7.1	1989	0.18
33	1981	31	1977	6.7	1978	0.18
34	1977	30	1963	6.3	1968	0.18
35	1963	30	1978	6.0	1964	0.18
36	1986	29	1986	5.8	1961	0.17
37	1973	29	1961	4.8	1972	0.14
38	1961	28	1958	4.6	1958	0.14
Mean		44		10.3		0.23
Median		46		10.9		0.23

Extreme Year = 1969 Typical Year = 1970

Exhibit 5-2. Rainfall and Runoff Parameters for Typical and Extreme Years

	No. of Events	Total Runoff (inches)	Average Overflow (in./event)
Maximum (all years)	68	15.1	0.33
1969	68	15.1	0.22
1956	53	13.1	0.25
1970	47	11.7	0.25
Mean (all years)	44	10.3	0.23
Median (all years)	46	10.9	0.23
1971	47	10.9	0.23
1988	52	10.9	0.21
1985	45	10.4	0.23
1979	43	10.7	0.25
Minimum (all years)	28	4.6	0.14

Event Statistics. Information may also be developed on the characteristics of individual storm events for a site. If the sequence of hourly rainfall volumes from the existing gages is grouped into separate events (i.e., each period of volume greater than zero that is preceded and followed by at least one period of zero volume would mark a separate event), then each storm event may be characterized by its duration, volume, average intensity, and the time interval between successive events. The event data can be analyzed using standard statistical procedures to determine the mean and standard deviation for each storm event, as well as probability distributions and recurrence intervals. The computer program SYNOP (Driscoll, et al., 1990) can be used to group the hourly rainfall values into independent rainfall events and calculate the storm characteristics and interval since the preceding storm.

Return Period/Volume Curves. The "return period" is the frequency of occurrence for a parameter (such as rainfall volume) of a given magnitude. The return period for a storm with a specific rainfall volume may be plotted as a probability distribution indicating the percent of storms with a total volume less than or equal to a given volume. For example, if approximately ten percent of the storm events historically deposit 1.5 inches of rain or more, and there are an average of 60 storm events per year, an average of 6 storm events per year would have a total volume of 1.5 inches or more, and the 1.5-inch rain event could be characterized as the "two-month storm." Return periods are discussed in *Hydrology and Floodplain Analysis* (Bedient and Huber, 1992).

Intensity-Duration-Frequency Curves. Duration can be plotted against average intensity for several constant storm return frequencies, in order to design hydraulic structures where short duration peak flows must be considered to avoid local flooding. For example, when maximizing in-system storage (under the NMC), the selected design event should ensure that backups in the collection system, which cause flooding, are avoided. Intensity-duration-frequency (IDF) curves are developed by analyzing an hourly rainfall record so as as to compute a running sum of volumes for consecutive hours equal to the duration of interest. The volumes for that duration are then ranked, and based on the length in years of the record, the recurrence interval for any rank is determined. This procedure is used to calculate the local value for design storms such as a 1 -year, 6-hour design condition. Development and use of IDF curves is discussed in *Hydrology and Floodplain Analysis* (Bedient and Huber, *1992)* and the *Water Resources Handbook* (Mays, 1996).

Local Rain Gage Data

In order to calibrate and verify runoff and water quality models, it is also necessary to analyze rainfall data for specific storm events in which CSO quality and flow are sampled.

Local rain gage data can be used to assess the applicability of the long-term record of the site. For example, Exhibit 5-3 presents six weeks of local rainfall data from three tipping bucket gages (labeled A, B, and C in Exhibit 5-4). Comparison with regional rainfall records indicates that the average value of the three gages was close to the regional record with only slight variations among gages.

Exhibit 5-3. 1993 Rainfall Data for a 5,305 Acre Drainage Area

Storm Event	Date	Gage A (inches)	Gage B (inches)	Gage C (inches)	Regional Record of Rainfall (inches)	Duration (hours)	Intensity (in/hr)
1	4/6	0.58	0.58	0.62	0.59	4.8	0.12
2	4/14 M	0.22	0.17	0.19	0.19	1.5	0.13
3	4/21	0.11	0.12	0.08	0.10	1.4	0.07
4	4/28 M	0.87	1.20	1.05	1.04	2.5	0.42
5	5/5	0.12	0.18	0.12	0.14	1.5	0.09
6	5/8	0.47	0.40	0.42	0.43	9.4	0.05
7	5/11	0.50	0.45	0.45	0.47	4.5	0.10
8	5/13 M	0.44	0.31	0.22	0.32	0.8	0.40
9	5/14	0.48	0.43	0.52	0.48	4.3	0.11
	Total	**3.79**	**3.84**	**3.67**	**3.70**	**30.7**	**0.12**

M = event selected for detailed water quality monitoring

Storm events 2, 4, and 8 were selected for detailed water quality sampling and analysis. Subsequent analyses of CSS flow and CSS water quality data for this example are discussed in Sections 5.3.3 and 5.4.2, respectively.

In cases where local rain gages are placed near but not exactly at the locations where CSS flow and quality is being monitored, rainfall data from several nearby rain gage locations can be interpolated to estimate the rainfall at the sampling location. The inverse distance weighting method (see box on next page) can be used to calculate the rainfall over a CSS sampling location in watershed 4 in Exhibit 5-4.

It may also be possible to use radar imaging data to estimate rainfall intensities at multiple locations throughout the rainfall event.

Inverse Distance Weighting Method

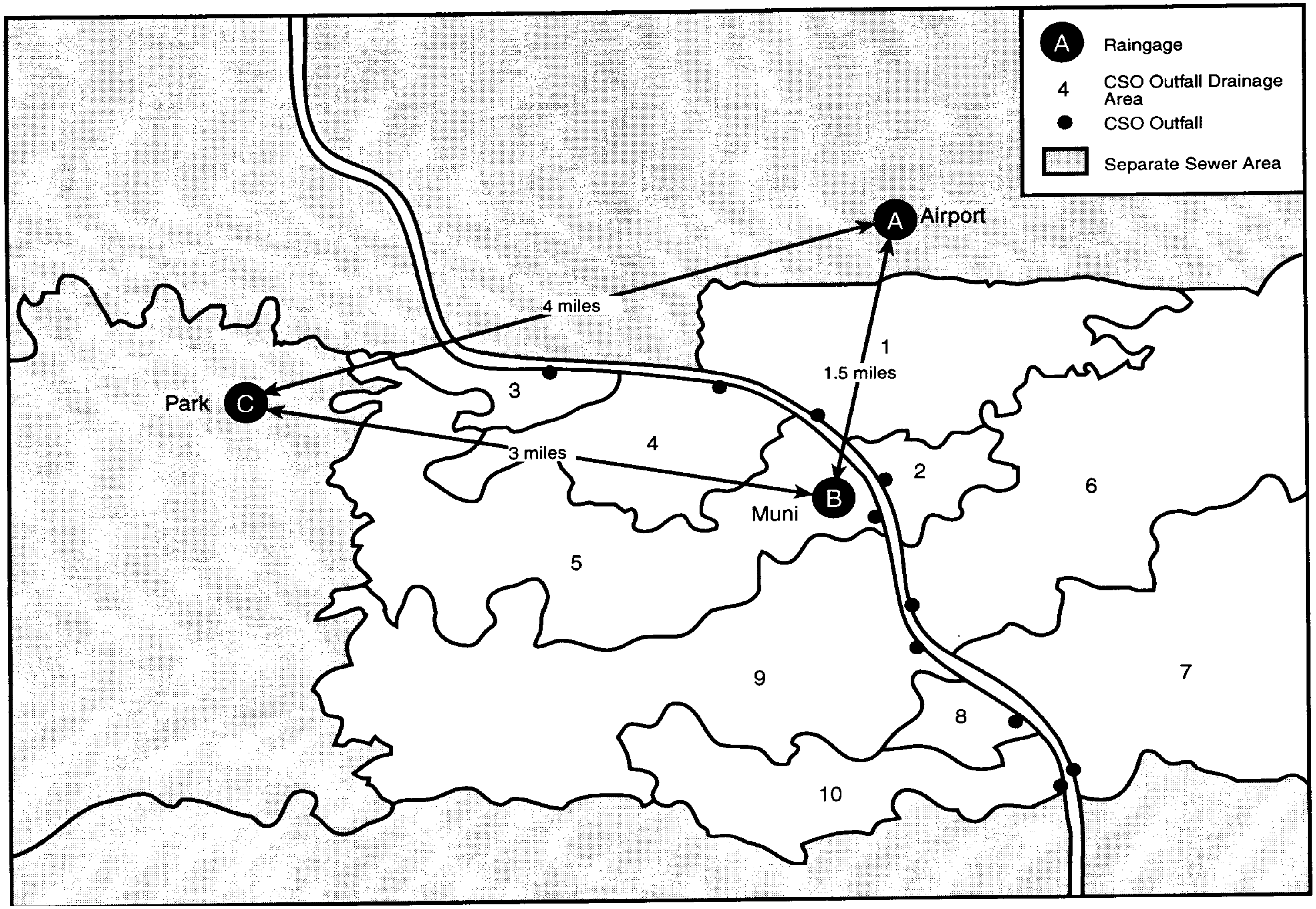
Using this method, the estimated precipitation at the sampling location is calculated as the weighted average of the precipitation at the surrounding rain gages. The weights are the reciprocals of the squares of the distances between the sampling location and the rain gages. The estimated rainfall at the sampling location is calculated by summing the precipitation times the weight for each rain gage and dividing by the sum of the u-eights. For example, if the distance between the sampling location in watershed 4 and ram gage A is X, rain gage B is Y, and rain gage C is Z and the precipitation at each rain gage is P_A, P_B, and P_C, then the precipitation at the sampling location in watershed 4 can be estimated by:

$$P_4 = [(P_A \times \frac{1}{X^2}) + (P_B \times \frac{1}{Y^2}) + (P_C \times \frac{1}{Z^2})] \;/\; (\frac{1}{X^2} + \frac{1}{Y^2} + \frac{1}{Z^2})$$

If P_A, P_B, and P_C are 0.87, 1.20, and 1.05 inches, respectively, and X, Y, and Z are 1.5, 1.0, and 2.5 miles, respectively, then

$$P_4 = [(0.87 \times \frac{1}{(1.5)^2}) + (1.20 \times \frac{1}{(1.0)^2}) + (1.05 \times \frac{1}{(2.5)^2})] \;/\; (\frac{1}{(1.5)^2} + \frac{1}{(1.0)^2} + \frac{1}{(2.5)^2}) = 1.09 \text{ inches}$$

Exhibit 5-4. Rain Gage Map for Data Presented in Exhibit 5-3



Not to Scale

5.3 FLOW MONITORING IN THE CSS

Accurate flow monitoring is critical to understanding the hydraulic characteristics of a CSS and predicting the magnitude, frequency, and duration of CSOs. Monitoring flows in CSSs can be difficult because of surcharging, backflow, tidal flows, and the intermittent nature of overflows. Selecting the most appropriate flow monitoring technique depends on site characteristics, budget constraints, and availability of personnel. This section outlines options for measuring CSS flow and discusses how to organize and analyze the data collected.

5.3.1 Flow Monitoring Techniques

Flow measurement techniques vary greatly in complexity, expense, and accuracy. This section describes a range of manual and automated flow monitoring techniques. Exhibit 5-5 summarizes their advantages and disadvantages.

Manual Methods

The simplest flow monitoring techniques include manual measurement of velocity and depth, use of bottle boards and chalking (see Example 5-1), and dye testing. Manual methods are difficult during wet weather, however, since they rely extensively on labor-intensive field efforts during storm events and do not provide an accurate, continuous flow record. Manual methods are most useful for instantaneous flow measurement, calibration of other flow measurements, and flow measurements in small systems. They are difficult to use for measuring rapidly changing flows because numerous instantaneous measurements must be taken at the proper position to correctly estimate the total flow.

Measuring Flow Depth

Primary flow devices, such as weirs, flumes, and orifice plates, control flow in a portion of pipe such that the flow's depth is proportional to its flow rate. They enable the flow rate to be determined by manually or automatically measuring the depth of flow. Measurements taken with these devices are accurate in the appropriate hydraulic conditions but are not accurate where surcharging or backflow occur. Also, the accuracy of flow calculations depends on the reliability of depth-sensing equipment, since small errors in depth measurement can result in large errors in

Exhibit 5-5. CSO Flow Monitoring Devices

Monitoring Method	Description	Advantages	Disadvantages
Manual Methods			
Timed Flow	Timing how long it takes to fill a container of a known size	• Simple to implement • Little equipment needed	• Labor-intensive • Suitable only for low flows
Dilution Method	Injection of dye or saline solution in the system and measuring the dilution	• Accurate for instantaneous flows	• Not appropriate for continuous flow • Outside contaminants could affect results
Direct Measurement	Use of a flow meter and surveying rod to manually measure flow and depth	• Easy to collect data	• Labor-intensive • Multiple measurements may be needed at a single location
Chalking and Chalking Boards	Blowing chalk into a CSO structure, or installation of a board with a chalk line. The chalk is erased to the level of highest flow	• Easy to implement	• Provides only a rough estimate of depth
Bottle Boards	Installation of multiple bottles at different heights where the highest filled bottle indicates the depth of flow	• Easy to implement	• Provides only a rough estimate of depth
Primary Flow			
Weir	Device placed across the flow such that overflow occurs through a notch. Flow is determined by the depth behind the weir	• Many CSOs have an existing weir • More accurate than other manual measurements	• Cannot be used in full or nearly full pipes • Somewhat prone to clogging and silting
Flume	Chute-like structure that allows for controlled flow	• Accurate estimate of flow • Less prone to clogging than weirs	• Not appropriate for backflow conditions • More expensive than weirs
Orifice Plate	A plate with a circular or oval opening designed to control flow	• Can measure flow in full pipes • Portable and inexpensive to operate	• Prone to solids accumulation
Depth Sensing			
Ultrasonic Sensor	Sensor mounted above the flow that measures depth with an ultrasonic signal	• Generally provide accurate measures	• May be impacted by solids or foam on flow surface
Pressure Sensor	Sensor mounted below the flow which measures the pressure exerted by the flow	• Generally provide accurate measures	• Require frequent cleaning and calibration
Bubbler Sensor	Sensor that emits a stream of bubbles and measures the resistance to bubble formation	• Generally provide accurate measures	• Require frequent cleaning to prevent clogging
Float Sensor	Sensors using a mechanical float to measure depth	• Generally provide accurate measures	• Must be accurately calibrated prior to use and regularly checked for fouling
Velocity Meters			
Ultrasonic	Meter designed to measure velocity through a continuous pulse	• Instrument does not interfere with flow • Can be used in full pipes	• More expensive than other equipment
Electromagnetic	Meter designed to measure velocity through an electromagnetic process	• Instrument does not interfere with flow • Can be used in full pipes	• More expensive than other equipment

flow rate calculation. Monitoring devices need to be resistant to fouling and clogging because of the large amounts of grit and debris in a CSS.

Depth-sensing devices can be used with pipe equations or primary flow and velocity-sensing devices to determine flow rates. They include:

- ***Ultrasonic Sensors,*** which are typically mounted above the flow in a pipe or open channel and send an ultrasonic signal toward the flow. Depth computations are based on the time the reflected signal takes to return to the sensor. These sensors provide accurate depth measurements but can be affected by high suspended solid loads or foaming on the water surface.

- ***Pressure Sensors,*** which use transducers to sense the pressure of the water above them. They are used with a flow monitor that converts the pressure value to a depth measurement.

- ***Bubbler Sensors,*** which emit a continuous stream of fine bubbles. A pressure transducer senses resistance to bubble formation, converting it to a depth value. These devices provide accurate measurements. The bubble tube can clog, however, and the device itself requires frequent calibration.

- ***Float Sensors,*** which sense depth using a mechanical float, often within a chamber designed to damp out surface waves. Floats can clog with grease and solid materials and are, therefore, not commonly used to sense flow in sewers.

Example 5-1. Flow Monitoring

A bottle rack is used to determine the approximate depth of overflows from a 36-inch combined sewer in an overflow manhole (Exhibit 5-6). The overflow weir for this outfall is 12 inches above the invert of the sewer, and flows below this level are routed out the bottom of the structure to the interceptor and the wastewater treatment plant. Any flow overflowing the 12-inch weir is routed to the 42-inch outfall sewer. Attached to the manhole steps, the bottle rack approximates the flow level in the manhole by the height of the bottles that are filled. This outfall has potential for surcharging because of flow restrictions leading to the interceptor. Consequently, the bottle rack extends well above the crown of the outfall sewer. After each rainfall, a member of the monitoring team pulls the rack from the manhole, records the highest bottle filled, and returns the rack to the manhole, Exhibit 5-7 presents depth data for the nine storms listed in Exhibit 5-3.

Storm 3, which had 0.1 inch of rain in 85 minutes, was contained at the outfall with no overflow, although it did overflow at other locations. Storm 5, with an average volume of 0.14 inches and an average intensity of 0.09 in/hour, had a peak flow depth of approximately six inches above the weir crest.

It is instructive to examine the individual rain gages (located as indicated in Exhibit 5-4) and compare them to the flow depths. Rain gage A indicated that Storms 3 and 5 had similar depths and that 3 was slightly more intense. Why, then, did Storm 5 cause an overflow, while Storm 3 did not? Rain gage B, which lies nearer to the outfall, indicates 50 percent more volume and 50 percent higher intensity for storm 5. Using only rain gage A in calibrating a hydraulic model to the outfall for storms 3 and 5 could have posed a problem. Because a bottle board indicates approximate maximum flow depth, not duration or flow volume, it is not sufficient to calibrate most models.

Storms 4 and 8 caused flow depth to surcharge, or increase above the crown of the pipe. Both storms occurred during late afternoon when sanitary sewer flows are typically highest, potentially exacerbating the overflow, The surcharging pipe indicates that flow measurements will be difficult for large storms at this location. Further field investigations will be necessary to define the hydraulics of this particular outfall and intercepting device, Because of safety considerations in gaming access to this location, the monitoring team used only the bottle board during the early monitoring period. Later, the team instailed a velocity meter and a series of depth probes to determine a surface profile.

Exhibit 5-6. Illustration of a Bottle Board Installation

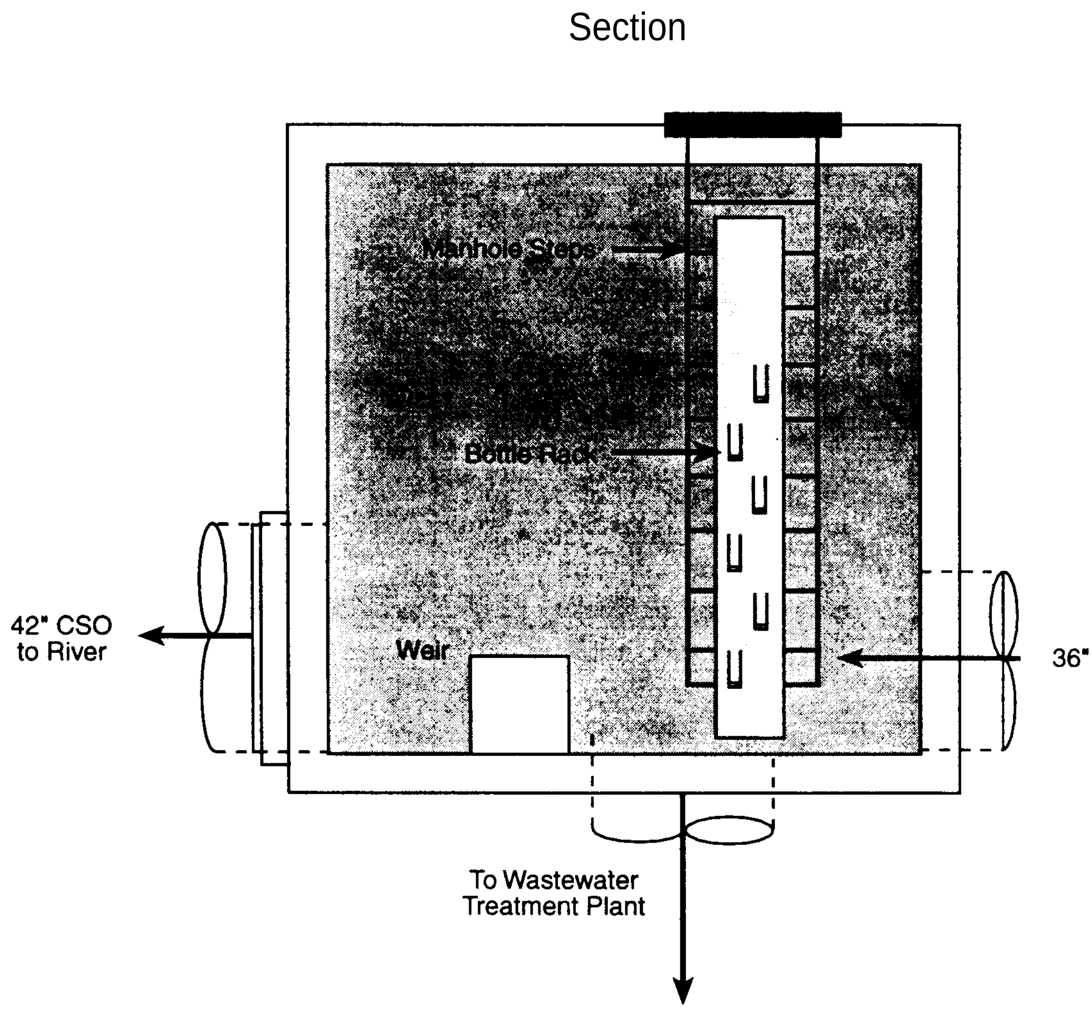


Exhibit 5-7. Example Outfall Bottle Rack Readings

Storm Event	Manhole Flow Level (inches)	Height of Overflow (inches)
1	21	9
2	18	6
3	12	none
4	48	36 (surcharge)
5	18	6
6	18	6
7	30	18
8	42	30 (surcharge)
9	24	12

Using depth measurement data, pipe equations can be applied to develop flow estimates. The Hazen-Williams equation, Manning equation, and similar equations can be useful for estimating flow capacity of the system and performing a preliminary flow analysis of the CSS. The Hazen-Williams equation is generally used for pressure conduits, while the Manning equation is usually used in open-channel situations (Viessman, 1993). The Hazen-Williams equation is:

$$V = 1.318\ C(R)^{0.63}\ (S)^{0.54}$$

where:

V = mean flow velocity
C = Hazen-Williams coefficient, based on material and age of the conduit
R = hydraulic radius
S = slope of energy gradeline (ratio of rise to run).

The Manning Equation is:

$$V = (1.49/n)\ (R)^{0.666}\ (S)^{0.5}$$

where:

V = mean flow velocity
n = Manning roughness coefficient, based on type and condition of conduit
R = hydraulic radius
S = slope of energy gradeline (ratio of rise to run).

The volumetric flow rate (Q) is computed by:

$$Q = V\ A$$

where:

V = mean flow velocity
A = cross-sectional area.

Since the calculations are based on the average upstream characteristics of the pipe, personnel should measure depth at a point in the sewer where there are no bends, sudden changes in invert elevation, or manholes immediately upstream. These features can introduce large errors into the flow estimate. Anomalies in sewer slope, shape, or roughness also can cause large errors (50 percent and greater) in flow measurement. However, in uniform pipes, a careful application of these formulas can measure flows with an error as low as 10 to 20 percent (ISCO, 1989). The permittee can improve the accuracy of the equation somewhat by calibrating it initially, using measurements of velocity and depth to adjust slope and roughness values.

Velocity Meters

Velocity meters use ultrasonic or electromagnetic technology to sense flow velocity at a point, or in a cross section of the flow. The velocity measurement is combined with a depth value (from a depth sensor attached to the velocity meter) to compute flow volume. Velocity meters can measure flows in a wider range of locations and flow regimes than depth-sensing devices used with primary flow devices, and they are less prone to clogging. They are comparatively expensive, however, and can be inaccurate at low flows and when suspended solid loads vary rapidly. One type of meter combines an electromagnetic velocity sensor with a depth sensing pressure transducer in a single probe. It is useful for CSO applications because it can sense flow in surcharging and backflow conditions. This device is available as a portable model or for permanent installation.

Measuring Pressurized Flow

Although sewage typically flows by gravity, many CSSs use pumping stations or other means to pressurize their flow. Monitoring pressurized flow requires different techniques from those used to monitor gravity flows. If a station is designed to pump at a constant rate, the flow rate through the station can be estimated from the length of time the pumps are on. If a pump empties a wet well or cavern, the pumping rate can be determined by measuring the change in water level in the wet well. If the pump rate is variable, or pump monitoring time is insufficient to measure flow, then full-pipe metering is required.

Measuring Flow in Full Pipes

Full pipes can be monitored using orifices, venturis, flow nozzles, turbines, and ultrasonic, electromagnetic, and vortex shedding meters. Although most of these technologies require disassembling the piping and inserting a meter, several types of meters strap to the outside of a pipe and can be moved easily to different locations. Another measurement technique involves using two pressure transducers, one at the bottom of the pipe, and one at the top of the pipe or in the manhole just above the pipe crown. Closed pipe metering principles are discussed fully in *The Flow*

Measurement Engineering Handbook (Miller, 1983). Manufacturers' literature should be consulted for installation requirements.

5.3.2 Conducting the Flow Monitoring Program

Most flow monitoring involves the use of portable, battery-operated depth and velocity sensors, which are left in place for several storm events and then moved elsewhere. For some systems, particularly small CSSs, the monitoring program may involve manual methods. In such cases, it is important to allocate the available personnel and prepare in advance for the wet weather events.

Although temporary metering installations are designed to operate automatically, they are subject to clogging in CSSs and should be checked as often as possible for debris.

Some systems use permanent flow monitoring installations to collect data continuously at critical points. Permanent installations also can allow centralized control of transport system facilities to maximize storage of wastewater in the system and maximize flow to the treatment plant. The flow data recorded at the site may be recovered manually or telemetered to a central location.

To be of use in monitoring CSSs, flow metering installations should be able to measure all possible flow situations, based on local conditions. In a pipe with smooth flow characteristics, a weir or flume in combination with a depth sensor or a calibrated Manning equation may be sufficient. Difficult locations might warrant redundant metering and frequent calibration. The key to successful monitoring is combining good design and judgment with field observations, the appropriate metering technology, and a thorough meter maintenance and calibration schedule.

5.3.3 Analysis of CSS Flow Data

The CSS flow data can be evaluated to develop an understanding of the hydraulic response of the system to wet weather events and to answer the following questions for the monitored outfalls:

- Which CSO outfalls contribute the majority of the overflow volume?
- What size storm can be contained by the regulator serving each outfall? What rainfall amount is needed to initiate overflow? Does this containment capacity vary from storm to storm?
- Approximately how many overflows would occur and what would be their volume, based on a rainfall record from a different year? How many occur per year, on average, based on the long-term rainfall record?

Extrapolating from the monitored period to other periods, such as a rainfall record for a year with more storms or larger volumes, requires professional judgment and familiarity with the data. For example, as shown in Exhibit 5-8, the flow regulator serving Outfall 4 prevented overflows during Storm 3, which had 0.10 inch of rain in 1.4 hours. However, approximately half of the rainfall volume overflowed from Storm 5, which had 0.14 inch in 1.5 hours. From these data, the investigator might conclude that, depending on the short-term intensity of the storm or the antecedent moisture conditions, Outfall 4 would contain a future storm of 0.10 inches but that even slightly larger storms would cause an overflow. Also, Exhibit 5-8 indicates that a storm even as small as Storm 3 can cause overflows at the other outfalls.

Exhibit 5-8. Total Overflow Volume

Storm	Rainfall Depth (R) (inches)	Duration (hours)	Outfall (and service area size, in acres)									
			#l (659 acres)		#4 (430 acres)		#5(500 acres)		#7 (690 acres)		#9 (1,060 acres)	
			V	V/R	V	V/R	V	V/R	V	V/R	V	V/R
1	0.59	4.8	0.24	0.41	0.39	0.65	0.27	0.46	0.50	0.85	na	na
2	0.19	1.5	0.07	0.37	0.085	0.45	na	na	0.14	0.72	0.072	0.38
3	0.10	1.4	na	na	0.00	0.00	0.04	0.41	0.06	0.56	0.045	0.45
4	1.04	2.5	0.62	0.60	0.832	0.80	0.39	0.73	0.81	0.77	0.44	0.67
5	0.14	1.5	0.06	0.43	0.071	0.51	0.05	0.37	0.102	0.73	0.051	0.36
6	0.43	9.4	0.19	0.44	0.195	0.45	0.18	0.43	0.361	0.84	0.23	0.53
7	0.47	4.5	0.26	0.55	0.32	0.68	0.16	0.34	0.334	0.71	0.2	0.42
8	0.32	0.8	na	na	0.252	0.79	0.15	0.46	0.25	0.78	0.141	0.44
9	0.48	4.3	0.26	0.54	0.32	0.66	0.14	0.29	0.29	0.60	0.17	0.35
Average	0.42	3.41	0.24	0.48	0.27	0.55	0.17	0.43	0.32	0.73	0.17	0.45

V = overflow volume (inches depth when inches of overflow is spread over drainage area)
R = rainfall depth (inches)
na = no measurement available

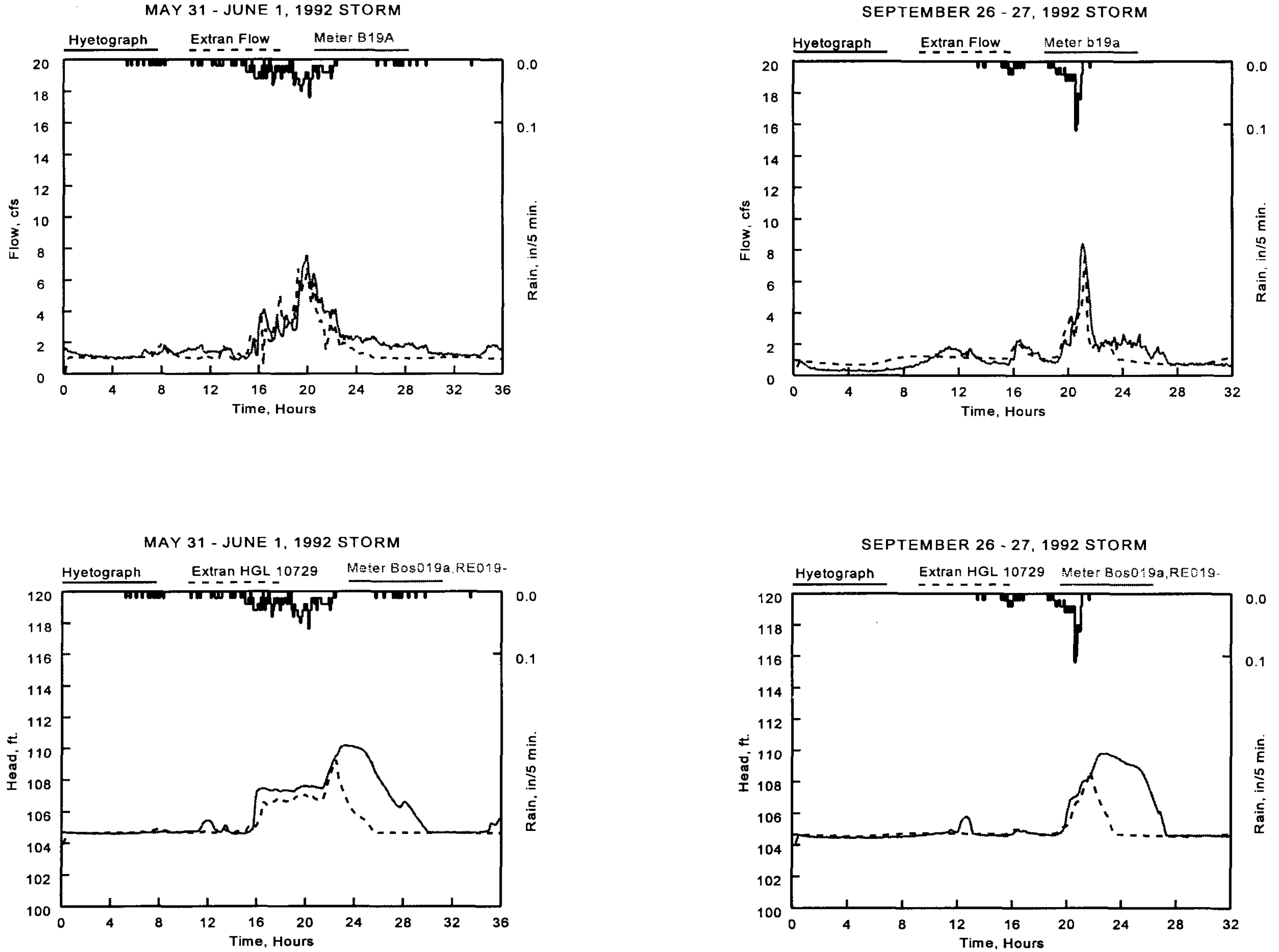
Comparing the overflow volumes of different outfalls indicates which outfalls contribute the bulk of the overflow volume and, depending on loading measurements, may contribute most heavily to water quality problems. To compare the hydraulic performance of different outfalls, flows should be normalized against the drainage area and rainfall. Provided that rainfall data are representative of the area's rainfall, inches of overflow (spread over the discharge subarea) per inch of rainfall constitutes a useful statistic. Exhibit 5-8 presents the overflow volumes in inches and the ratio of depth of overflow to depth of rain (V/R).

For each outfall, V/R varies with the storm depending on the number of antecedent dry days, the time of the storm, and the maximum rainfall intensity. V/R also varies with the outfall depending on land characteristics such as its impervious portion, the hydraulic capacity upstream and downstream of the flow regulator, the operation of the flow regulator, and features that limit the rate at which water can enter the system draining to that overflow point. Because of the large number of factors affecting variations in V/R, small differences generally provide little information about overflow patterns. However, certain patterns, such as an increase in V/R over time or large differences in V/R between storms or between outfalls, may indicate design flaws, operational problems, maintenance problems, or erroneous flow measurements, or a rainfall gage that does not represent the average depth of rain falling on the discharge subarea.

In addition to supporting an analysis of CSO volume, flow data can be used to create a plot of flow and head for a selected conduit during a storm event, as shown in Exhibit 5-9. These plots can be used to illustrate the conditions under which overflows occur at a specific outfall. They can also be used during CSS model calibration and verification (see Chapter 7).

Exhibits 5-8 and 5-9 (representing different CSS monitoring programs) illustrate some of the numerous methods available for analyzing CSO flow monitoring data. Additional methods include plotting regressions of overflow volume and rainfall to interpret monitoring data and identify locations that will cause difficulty in calibrating a model. For this type of regression, the y-intercept defines the rainfall needed to cause an overflow and the slope roughly defines the gross runoff coefficient for the basin. Flow data can also be used to tabulate CSO volumes and frequencies during the monitored time period and to compare the relative volumes and frequencies from different

Exhibit 5-9. Example CSS Plots of Flow and Head versus Time



monitoring sites in the CSS. Data are plotted, tabulated, and analyzed prior to a modeling assessment (described in Chapter 7).

5.4 WASTEWATER MONITORING IN THE CSS

Collecting and analyzing CSS wastewater samples is essential to characterizing an overflow and determining its impact on a receiving water body. Wastewater monitoring information can be used to:

- Indicate potential exceedances of water quality criteria
- Indicate potential human health and aquatic life impacts
- Develop CSO quality models
- Assess pretreatment and pollution prevention programs as part of the NMC.

This section outlines various methods for collecting, organizing, and analyzing CSS wastewater data. Sampling during wet weather events involves some factors that are not a significant concern during dry weather. These additional considerations are discussed in the section on sample program organization for receiving water quality monitoring (Section 6.3.1).

5.4.1 Water Quality Sampling

In general, wastewater **sample types** fall into the following two categories:

- Grab samples
- Composite samples.

Grab Sampling. A grab sample is a discrete, individual sample collected over a maximum of 15 minutes. Grab samples represent the conditions at the time the sample is taken and do not account for variations in quality throughout a storm event. Multiple grab samples can be gathered at a station to define such variations, although costs increase due to additional labor and laboratory expenses.

Composite Sampling. A composite sample is formed by combining samples collected over a period of time, or representing more than one specific location or depth. Composite sampling provides data representing the overall quality of combined sewage averaged over a storm event. The composited sample can be collected by continuously filling a container throughout the time period, collecting a series of separate aliquots, or combining individual grab samples from separate times, depths, or locations. Common types of composite samples include:

- ***Time composite samples*** - Composed of discrete sample aliquots, of constant volume, collected at constant time intervals.
- ***How-weighted composite samples*** - Composed of samples combined in relation to the amount of flow observed in the period between the samples.

Flow-weighted cornpositing can be done in two ways:

- Collect samples at equal time intervals at a volume proportional to the flow rate (e.g., collect 100 ml of sample for every 100 gallons of flow that passed during a lo-minute interval).
- Collect samples of equal volume at varying times proportional to the flow (e.g., collect a 100 ml sample for each 100 gallons of flow irrespective of time).

The second method is preferable for sampling wet weather flows, since it results in the greatest number of samples when the flow rate is the highest. More detailed information on methods of flow weighting is presented in the *NPDES Storm Water Sampling Guidance Document* (U.S. EPA, 1992).

Grab and composite samples can be collected using either of two **sample methods:** manual and automatic.

Manual Sampling. Manual samples are usually collected by an individual using a hand-held container. This method requires minimal equipment and allows field personnel to record additional observations while the sample is collected. Because of their special characteristics, certain pollutants should be collected manually. For example, fecal streptococcus, fecal coliform, and chlorine have very short holding times (i.e., 6 hours), pH and temperature need to be analyzed immediately, and oil and grease can adhere to the sampling equipment and cause inaccurate measurements. Volatile compounds *must* be collected manually according to standard procedures since these compounds will likely volatilize as a result of agitation during automatic sampler collection (APHA, 1992).

Manual sampling can be labor-intensive and expensive when the sampling program is long-term and involves many locations. Personnel must be available around the clock to sample storm events. Safety issues or hazardous conditions may affect sampling at certain locations.

Automated Sampling. Automated samplers are useful for CSS sampling because they can be programmed to collect multiple discrete samples as well as single or multiple composited samples. They can collect samples on a timed basis or in proportion to flow measurement signals from a flow meter. Although automated samplers require a large investment, they can reduce the amount of labor required in a sampling program and increase the reliability of flow-weighted cornpositing.

Automated samplers have a lower compartment, which holds glass or plastic sample containers and an ice well to cool samples, and an upper part, containing a microprocessor-based controller, a pump assembly, and a filling mechanism. The samplers can operate off of a battery, power pack, or electrical supply. More expensive samplers have refrigeration equipment and require a 120-volt power supply. Many samplers can be connected to flow meters that will activate flow-weighted cornpositing programs, and some samplers are activated by inputs from rain gages.

Automated samplers also have limitations:

- Some pollutants (e.g., oil and grease) cannot be sampled by automated equipment unless only approximate results are desired.
- The self-cleaning capability of most samplers provides reasonably separate samples, but some cross-contamination is unavoidable because water droplets usually remain in the tubing.
- Batteries may run down or the power supply may fail.

- Debris in the sewer, such as rags and plastic bags, can block the end of the sampling line, preventing sample collection. When the sampling line is located near a flow meter, this clogging can also cause erroneous flow measurements. Samplers and meters should be checked during storms and must be tested and serviced regularly. If no field checks are made during a storm event, data for the entire event may be lost.

- The sample nozzles of many automatic samplers do not have the velocity capabilities necessary for picking up the sand and gravel in untreated CSO flows.

Sampling Strategies

In developing a sampling strategy, the permittee should consider the timing of samples and sampling intervals (i.e., duration of time between the collection of samples). Since pollutant concentrations can vary widely during a storm event, the permittee should consider sampling strategies that include pre-storm, first flush, peak flow, recovery, and post-storm samples. For example, the permittee could take individual grab samples at each site during the different storm stages. Another sampling regime the permittee can use is taking a series of samples during the stages at each site:

- Pre-storm grab sample
- Composite samples collected during first flush
- Composite samples collected during peak flow
- Composite samples collected after peak flows
- Post-storm grab sample.

A third possible sampling regime could include a first flush composite taken over the first 30 minutes of discharge, followed by a second composite over the next hour of discharge, followed by a third composite for the remainder of the storm. To characterize first flush, a sample should be collected as close to the beginning of the CSO event as feasible. Appropriate sampling intervals depend on such factors as drainage area sizes, slopes, land uses, and percent imperviousness.

Contaminants Requiring Special Collection Techniques

The above discussion focuses on CSS sampling for contaminants with no special collection requirements. The following contaminants have special handling requirements (as identified in 40 CFR Part 136):

- ***Bacteria*** - Because samples collected for bacteria analysis cannot be held for more than six hours, they must be collected manually. Bacteria samples are collected directly into a sterile container or plastic bag, and it is important not to contaminate the sample by touching it. Often the samples are preserved with sodium thiosulfate.

- ***Volatile Organic Compounds (VOCs)*** - Samples analyzed for VOCs are collected directly into special glass vials. Each vial must be filled so that there is no air space into which the VOCs can volatilize and be lost.

- ***Oil and Grease*** - Samples analyzed for oil and grease must be collected by grab sample using a glass jar with a Teflon-coated lid. Samples are preserved by lowering the pH below 2.0 using a strong acid.

- ***Dissolved Metals*** - Samples collected for dissolved metals analysis must be filtered immediately after sample collection and before preservation.

The monitoring program may also include toxicity testing, in which the acute and chronic impacts to aquatic life are determined. Toxicity testing procedures for wet weather discharges are in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA, 1991a).

Sample Preparation and Handling

Sample bottles are typically supplied by the laboratory that will perform the analysis. Laboratories may provide properly cleaned sampling containers with appropriate preservatives. For most parameters, preservatives should be added to the container after the sample. To avoid hazards from fumes and spills, acids and bases should not be in containers without a sample. If preservation involves adjusting sample pH, the preserved sample should always be checked to make sure it is at the proper pH level. The maximum allowed holding period for each analysis is specified in Table II of 40 CFR Part 136. Acceptable procedures for cleaning sample bottles, preserving their contents, and analyzing for appropriate chemicals are detailed in various methods manuals, including APHA (1992) and U.S. EPA (1979).

Water samplers, sampling hoses, and sample storage bottles should always be made of materials compatible with the pollutants being sampled. For example, when sampling for metals, bottles should not have metal components that can contaminate the samples. Similarly, bottles and caps used for organic samples should be made of materials not likely to leach into the sample.

Sample Volume, Preservation, and Storage. Sample volumes, preservation techniques, and maximum holding times for most parameters are specified in 40 CFR Part 136. Refrigeration of samples during and after collection at a temperature of 4°C is required for most analyses. Manual samples are usually placed in a cooler containing ice or an ice substitute. Most automated samplers have a well next to the sample bottles to hold either ice or ice substitutes. Some expensive samplers have mechanical refrigeration equipment. Other preservation techniques include pH adjustment and chemical fixation. pH adjustment usually requires strong acids and bases, which should be handled with extreme caution.

Sample Labeling. Samples should be identified by waterproof labels containing enough information to ensure that each is unique. The information on the label should also be recorded in a sampling notebook. The label typically includes the following information:

- Name of project
- Date and time of sample collection
- Sample location
- Name or initials of sampler
- Analysis to be performed
- Sample ID number
- Preservative used
- Type of sample (grab, composite).

Sample Packaging and Shipping. Sometimes it is necessary to ship samples to the laboratory. Holding times should be checked prior to shipment to ensure that they will not be exceeded. While wastewater samples generally are not considered hazardous, some samples, such as those with extreme pH, require special procedures. Samples shipped through a common carrier or the U.S. Postal Service must comply with Department of Transportation Hazardous Material

Regulations (49 CFR Parts 171 - 177). Air shipment of samples classified as hazardous may also be covered by the Dangerous Goods Regulations (International Air Transport Association, 1996).

Samples should be sealed with chain-of-custody form seals in leak-proof bags and padded against jarring and breakage. Samples must be packed with an ice substitute to maintain a temperature of 4°C during shipment. Plastic or metal coolers make ideal shipping containers because they protect and insulate the samples. Accompanying paperwork such as the chain-of-custody documentation should be sealed in a waterproof bag in the shipping container.

Chain of Custody. The chain-of-custody form documents the changes of possession of a sample between time of collection and time of analysis. At each transfer of possession, both the relinquisher and the receiver sign and date the form in order to document transfer of the samples and to minimize opportunities for tampering. The container holding the samples can also be sealed with a signed tape or seal to document that the samples are uncompromised.

The sampler and the laboratory should retain copies of the chain-of-custody form. Contract laboratories often supply chain-of-custody forms with sample containers. The form is also useful for documenting which analyses will be performed on the samples. Forms typically contain the following information:

- Name of project and sampling locations
- Date and time that each sample was collected
- Names of sampling personnel
- Sample identification names and numbers
- Types of sample containers
- Analyses to be performed on each sample
- Additional comments on each sample
- Names of all personnel transporting the samples.

5.4.2 Analysis of Wastewater Monitoring Data

Since monitoring programs can generate large amounts of information, effective management and analysis of the data are essential. Even small-scale programs, such as those involving only a few CSS and receiving water monitoring locations, can generate an extensive amount of data. This section discusses tools for data analysis including spreadsheets, graphical presentations, and statistical analysis. (Data management is discussed in Section 4.8.2. Chapters 7 and 8 discuss more detailed data analysis during modeling.)

This section outlines an example analysis of data collected during three storms, where flow-weighted composite samples were collected and analyzed for BOD and TSS. Exhibit 5-10 shows average concentrations for each storm at the monitored outfalls; the small sample size does not provide statistically reliable information on the expected variability of these concentrations for other events. To estimate pollutant concentrations for a large set of storm events, expected values can be calculated by assuming a lognormal distribution. (The lognormal distribution has been shown to be applicable to CSO quality (Driscoll, 1986).) Exhibit 5-11 shows that the mean and median for the data are similar and are within typical ranges for CSO quality. The mean and median for the sampling data can be used with a lognormal distribution to compute the expected mean, median, and 90th-percentile value for a large data set of many storm events. If used as a basis for estimating impacts, the 90th-percentile values would be more conservative than the means for BOD and TSS since only 10 percent of the actual concentrations for these pollutants should exceed the 90th-percentile values.

Multiplying flow measurements (or estimates) by pollutant concentration values drawn from monitoring data gives the total pollutant load discharged during each storm at each outfall. Exhibit 5-12 lists pollutant loads for the three storms at each monitored outfall. As with flow data, these brief statistical summaries provide insight into the response of the system before any more involved computer modeling is performed. For example, the load in pounds of BOD and TSS discharged at each outfall, normalized to account for differences in rainfall depth or land area at each outfall, helps to identify differences in loading rates across outfalls over the long term. These loading factors can provide rough estimates of the loads from unmonitored outfalls that have land

Exhibit 5-10. Composite Sampling Data (mg/l)

Outfall	Storm #2		Storm #4		Storm #8		Average	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
1	115	340	80	200	110	240	102	260
4	96	442	94	324	120	350	103	372
5	128	356	88	274	92	288	103	306
7	92	552	82	410	71	383	82	448
9	110	402	120	96	55	522	95	340
Average	108	418	93	261	90	357	97	345

Exhibit 5-11. Pollutant Concentration Summary Statistics (mg/l)

	BOD	TSS
Mean	96.87	345.27
Median	94.00	350.00
Expected Mean*	97.16	352.53
Expected Median*	94.70	321.29
Expected 90th Percentile Value*	126.64	558.03
Typical CSO Characteristics[1]	60 - 220	270 - 550

*Projected statistic from sampling population (i.e., very large data set)
[1]Metcalf & Eddy, Inc., 1991.

uses or impervious areas similar to the monitored area. Finally, the total load per storm helps in comparing storms and projecting storm characteristics that would produce higher or lower loads. Pollutant loads are affected by the number of dry days and the number of days without a flushing storm because these factors represent a period when no severe scour activity occurred in the sewer system.

Three storms can indicate trends but do not provide enough data to characterize the load of the CSS or its individual source areas. As additional data are collected during the monitoring

Exhibit 5-12. Pollutant Loading Summary

		OUTFALL					
		1	4	5	7	9	TOTAL
STORM 2	Flow (MG)	1.39	0.99	na	2.55	2.07	7.00
composite	BOD (mg/l)	115	96	128	92	110	–
composite	TSS (mg/l)	340	442	356	552	402	–
load	BOD (lbs)	1,333	793	0	1,957	1,899	5,982
load	TSS (lbs)	3,941	3,649	0	11,739	6,940	26,269
STORM 4	Flow (MG)	11.67	9.72	5.31	15.09	12.64	54.43
composite	BOD (mg/l)	80	94	88	82	120	–
composite	TSS (mg/l)	200	324	274	410	96	–
load	BOD (lbs)	7,786	7,620	3,897	10,320	12,650	42,273
load	TSS (lbs)	19,466	26,265	12,134	51,599	10,120	119,584
STORM 8	Flow (MG)	na	2.95	2.00	4.68	4.07	13.70
composite	BOD (mg/l)	110	120	92	71	55	–
composite	TSS (mg/l)	240	350	288	686	522	–
load	BOD (lbs)	0	2,952	1,535	2,771	1,867	9,125
load	TSS (lbs)	0	8,611	4,804	26,775	17,719	57,909
Total Load*	BOD (lbs)	9,119	11,365	5,432	15,048	16,416	57,380
	TSS (lbs)	23,407	38,525	16,938	90,113	34,779	203,762
Area Load**	BOD	7	9	5	7	5	7
(lb/acre/storm)	TSS	18	30	17	44	11	24
Loading Rate	BOD	7,417	7,329	3,997	9,709	10,595	7,809
(lb/inch rain)	TSS	19,038	24,843	12,465	58,144	22,440	27,386

na = No flow data available. MG = millions of gallons.
load (lbs) = composite concentration (mg/l) x flow (MG) x 8.34 (conversion factor)
* For monitored storms
** Acreage data taken from Exhibit 5-8; for monitored storms (i.e., either 2 or 3)

program, estimates based on the data set become statistically more reliable because the size of the data sets increases. The additional information allows continual refinement of the permittee's knowledge of the system.

The example shown in Exhibit 5-13, involving bacteria sampling, illustrates the value of correlating flow and concentration data. Because automated samplers are not appropriate for collecting bacterial samples, manual grab samples were collected and analyzed for fecal coliform bacteria. During a single storm event, samples were collected from Outfall 1 at 30 minute intervals, beginning shortly after the storm started and ending with sample #6 approximately 2½ hours later. Peak flow occurred within the first 90 minutes. The fecal coliform concentration peaked in the first half hour and declined nearly one-hundredfold to the last sample, exhibiting a "first flush" pattern. The average concentration was 3.14×10^6 MPN/100 ml. To calculate total fecal coliform loading, flow measurements were multiplied by the corresponding grab sample concentrations at each half-hour interval, as shown in the right-hand column. The average concentration was also multiplied by the total flow for comparative purposes. This second calculation (1.79×10^{14} MPN) overestimates the total loading, primarily because it fails to correlate the decreasing bacteria level to the changing flows.

In many cases background conditions or upstream wet weather sources, such as separate storm sewer systems, may provide significant pollutant loads. Where possible, the permittee should try to assess loadings from non-CSO sources in order to fully characterize the receiving water impacts from CSOs. In some cases, these other sources may be outside the permittee's jurisdiction. If the permittee cannot obtain existing monitoring data on these sources, the permittee should consider monitoring these sources or entering into an agreement to have the appropriate party conduct the monitoring. The data analysis techniques discussed in this section apply equally well to other wet weather sources, although the pollutant concentrations in such sources may differ significantly.

Exhibit 5-13. Fecal Coliform Data for Outfall 1-Example Storm

Sample	Fecal Coliform Concentration (No./100 ml)*	CSO Flow 30 Minute Avg (cfs)	Load for 30 Minute Interval** (No. of Fecal Coliforms)
1	9.20×10^{6}	9.6	4.50×10^{13}
2	6.44×10^{6}	20.4	6.70×10^{13}
3	1.80×10^{6}	28.8	2.64×10^{13}
4	8.90×10^{5}	24.4	1.10×10^{13}
5	4.20×10^{5}	18.7	4.00×10^{12}
6	1.00×10^{5}	10.2	5.20×10^{11}
		Total Load	**1.54×10^{14}**

Average Concentration	Total Flow	Estimated Total Load***
3.14×10^{6}	112.1	1.79×10^{14}

* For CSOs, fecal coliform concentrations typically range from 2.0×10^{5} - 1.1×10^{6} colonies/100 ml (Metcalf & Eddy, 1991).
** Load = [Concentration (No./100 ml) x Total Flow (ml)] / 100 (since concentration is for 100 ml)
Total Flow (in ml) = cfs x 1800 (# of seconds in one 30-minute interval) x 28,321 (# of ml in one cf)
*** Load estimated by multiplying the average bacteria concentration by the total flow

Single composite samples or average data may be sufficient for a preliminary estimate of pollutant loadings from CSOs. Establishing an upper-bound estimate for such loads may be necessary in order to analyze short-term impacts based on short-term pollutant concentrations in the receiving water and to develop estimates for rarer events that have not been measured. A statistical distribution, such as normal or lognormal, can be developed for the data and mean values and variations can be estimated. These concentrations can be multiplied by measured flows or an assumed design flow to generate storm loads in order to predict rare or extreme impacts. Chapters 8 and 9 discusses further how to predict receiving water impacts.

5.5 SAMPLING AND DATA USE CASE STUDY

The case study in Example 5-2 presents an approach for sampling and data analysis used by Columbus, Georgia. The City found this approach useful in assessing CSO control options.[1]

Example 5-2. Sampling and Data Use Case Study

Columbus, Georgia

The City of Columbus, Georgia, in a CSO technology demonstration project, found significant correlation between the timing and volume of CSO pollutant loadings and the pre-storm dry weather conditions. These relationships can be used for:

1. quantifying annual and event loads to assess water quality impact,
2. developing alternatives and evaluating treatment controls, and
3. operating the disinfection process.

The Approach

The approach involves conducting discrete sampling (for flow and water quality) and using these sampling results and historical rainfall data to establish annual load and design rate relationships (% of annual quantity vs. design flow for volume and pollutants). The discrete sampling is timed to obtain more samples at the beginning of the storm event and fewer samples as the event progresses (pollutant weighted sampling}. Using this sampling plan in Columbus has resulted in data that show a significant correlation between the cumulative volume and pollutant mass for different pre-storm conditions.

Flow measurements can be correlated with rain rate measurements to establish a rainfall/runoff relationship for the total event and rainfall intensity. These pollutant and runoff correlations are used with the historical rainfall data to quantify annual pollutant loads and to define a relationship between design rate and annual quantity for control or treatment.

Using the Data

These relationships can be used to evaluate any specific control or various combinations of controls and define annual pollutant quantities for each control level. Types of controls include collection system maximization of flows and attenuation, storage, and direct treatment.

The entire procedure can be applied using simple spreadsheet methods or can be incorporated into more sophisticated modeling efforts.

The methodology can be used in either the presumption or demonstration approaches. In the presumption approach, where the objective is to treat the mass from 85% of the annual volume using primary clarification, the Columbus method can show that the objective can be reached with facilities at much smaller flow rates by applying better treatment to the more polluted, more frequent rainfall events. The net result can be less costly to facilities.

[1] The specific approach used by Columbus, GA, may not be appropriate for all CSO communities.

Example 5-2. Sampling and Data Use Case Study (Continued)

Cost-benefit levels of control can be determined from “knee-of-the curve” analyses using design rate relationships, and may represent different annual objectives for different pollutants to be reduced. For example:

- Treatment rate versus percent annual pollutant treated can be used to define the design storm criteria
- Treatment rate versus percent annual CSO volume treated can be used to define the level of high rate disinfection.

Alternatively, different levels of control can be evaluated to estimate the end-of-pipe loads and resulting in-stream concentrations for various flows. This provides a historical distribution of in-stream concentrations that can be compared to a waste load allocation to define statistical exceedances in a wet weather permit.

Finally, the evaluated treatment options can be compared using life-cycle costs and pollutant removal results, Fur chemical disinfection, the TSS loading relationship can be used in controlling the rate of disinfection. The disinfectant feed is varied according to the variation of incoming solids to accomplish the disinfection objective while minimizing the potential for overdosing.